

Improved RF Calibration Techniques: System Operating Noise Temperature Calibrations

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The system operating noise temperatures of the S-band research operational cone at the Venus Deep Space Station and the polarization diversity S-band cone at the Mars Deep Space Station are reported for the period June 1, 1971 through September 30, 1971. In addition, the performance of the multi-frequency X- and K-band cone on the ground at the Venus Deep Space Station is reported for X-band operation, as well as for X-band operation on the 64-m antenna at DSS 14, for the same period.

This article presents system operating noise temperature calibrations of the K-band system in the following configurations: before installation in the MXK cone (approximately 23 K), installed in the cone, with the cone on the ground (approximately 25 K), and with the cone installed on the 64-m antenna at the Mars Deep Space Station (approximately 29 K).

The system operating noise temperature performance of the low noise research cones at the Goldstone Deep Space Communications Complex is reported for the period June 1, 1971 (day 151) through September 30, 1971 (day 273). Most of the operating noise temperature calibrations were performed with the ambient termination technique (Ref. 1). The cones on which this technique¹ was used during this reporting period are:

- (1) S-band research operational (SRO) cone at DSS 13.
- (2) Polarization diversity S-band (PDS) cone at DSS 14.

- (3) Multi-frequency X- and K-band (MXK) cone at DSS 14 and DSS 13.

The averaged operating noise temperature calibrations for the SRO cone at DSS 13 and the PDS cone at DSS 14, and other calibration data, are presented in Table 1. Table 2 presents similar data for the MXK cone on the ground at DSS 13 and on the 64-m antenna at DSS 14. The calibration data were reduced with JPL computer program number 5841000, CTS20B. Measurement errors of each data point average are recorded under the appropriate number in the tables. The indicated errors are the standard deviation of the individual measurements and of

¹Most of the measurements were taken by DSS 13 (Venus) and DSS 14 (Mars) personnel.

the means, respectively. They do not include instrumentation systematic errors. The averages were computed using only data with:

- (1) Antenna at zenith.
- (2) Clear weather.
- (3) No RF spur in the passband.
- (4) Standard deviation of computed operating noise temperature due to measurement dispersion less than 0.15 K.

Table 1 shows that one data set was made at DSS 13 at the ALSEP frequency (2278.5 MHz) with the maser connected to a gain standard horn looking through a section of the 26-m antenna surface opened for this purpose. The antenna was at zenith and the system operating noise temperature in this configuration was 26.3 K.

Figures 1 and 2 are plots of the system operating noise temperatures of the SRO cone as a function of time in day numbers, at 2388 and 2278.5 MHz, respectively. Figure 3 is a similar plot with the maser connected to the gain standard horn at 2278.5 MHz. In all the figures in this report, data that satisfy the four conditions stated above are plotted as solid circles while data that fail one or more conditions are plotted as open circles.

The MXK cone was removed from the 64-m antenna at DSS 14 and taken to DSS 13 on June 28, 1971. The X-band system was reworked and the K-band system installed. This work was performed at DSS 13.¹ The cone was reinstalled on the 64-m antenna on August 5, 1971. Figure 4 shows a simplified block diagram of the MXK cone (modification 1) after installation of the K-band system. The block diagram is the same for both the X- and K-band systems. Table 2 shows X-band calibration data for the MXK cone both on the ground at DSS 13 and mounted on the 64-m antenna as modification 1. The first column presents data taken at DSS 13 with the cone on the ground just prior to the rework and K-band installation. In this condition only one horn was available and a set of 70 measurements was made over a 37-hour period at 8427.2 MHz. Figure 5 shows a graph of the system operating noise temperature as a function of time plotted as day number. Midday, local time, occurs at about day 188.8.

All the other columns in Table 2 present X-band data after the cone rework (mod. 1). Two calibration techniques

were used for these measurements. One was the ambient load technique referred to above, and the other was a similar technique which used an absorbing aperture load. The measurement method used for each set of data is indicated in Table 2.

Figure 6 is a graphical presentation of the data set in the second column of Table 2. This is the system operating noise temperature of the MXK cone (mod. 1) on the ground at DSS 13 with the maser connected to the reference horn at 8427.2 MHz plotted as a function of time in day numbers. Figures 7 through 10 show similar plots for: main horn, aperture load, 8427.2 MHz, cone on the ground; main horn, ambient load, 8427.2 MHz, cone on the ground; main horn, ambient load, 8415 MHz, cone on the ground; and main horn, ambient load, 8415 MHz, cone on the 64-m antenna, antenna at zenith, respectively.

Figure 11 shows the profile with elevation angle of the X-band system, MXK cone on the 64-m antenna at 8415 MHz. System temperature in Kelvins is plotted as a function of antenna angle with the subreflector correctly focused on the X-band main horn. This is the solid curve. The circled points are data obtained with the subreflector focused on the PDS cone. Each profile is the average of four data sets taken in August and September 1971. It must be noted that the difference in system temperature at zenith with the subreflector correctly and incorrectly positioned is about 6.25 K. This may be explained by the diagram of Fig. 12, where the solid ray paths show the geometry configuration with the subreflector focussed on the X-band main horn. The dotted lines trace the ray paths when the subreflector is focussed on the PDS cone. In this configuration some ground radiation is received by the X-band system.

System operating noise temperature calibrations of the K-band system were made before and after installation in the MXK cone. Before installation in the cone the system was measured at JPL, on the roof of building 238. K-band data with the cone on the ground were taken at DSS 13, and the antenna measurements were made with the cone mounted on the 64-m antenna at DSS 14. All calibrations were made at zenith at 15.3 GHz.

Table 3 presents averaged operating noise temperature calibrations in the various configurations. The calibration data were reduced with JPL computer program 5841000, CTS20B. Whenever possible measurement errors of each data point average are recorded under the appropriate number in the table. The indicated errors are the standard deviation of the individual measurements and of the

¹See "Waveguide Voltage Reflection Calibrations of the MXK Cone (Modification 1)" by P. D. Batelaan and "Microwave Maser Development," by R. Clauss and H. Reilly in this issue.

means, respectively. They do not include instrumentation systematic errors. The averages were computed using only data that satisfied the four conditions referred to above.

The first two columns of data in the table were taken on the roof of building 238 at JPL before the K-band system was installed in the cone. For these measurements the maser, waveguide and switch were in the same configuration that they have in the cone. Two measurement techniques were used, as shown in the table. One technique used a waveguide ambient load² and the other an absorbing aperture load. The average system temperature as measured by these techniques differed by 2.2 K, as shown in the table. This difference is probably due to the different pump frequency matches presented to the maser by the two techniques, and might be solved by incorporating a suitable filter in the maser input line.

Each of the above two measurement sets included a 24-hour run where data were taken every 30 min. Figure 13

²Batelaan, P., "Waveguide Voltage Reflection Calibrations of the MXK Cone (Modification 1)" in this issue.

is a plot of the aperture load data. System operating noise temperature is plotted as a function of time in day number (GMT) so that local mid-day occurs at about 0.8 day. The figure shows that the system temperature is lowest during the night and lies between 21 and 22 K for several hours. Highest temperatures, about 25.5 K, are recorded around mid-day with a gradual cooling in the afternoon. The weather was clear and dry during this measurement set. The data set using the ambient load technique showed similar characteristics.

The measurements made on the ground at DSS 13 show that the system temperature increased by 1.3 K (ambient load technique) and by 1.9 K (aperture load) when the system was built into the cone.

The system temperature was 29.1 K with the maser connected to the reference horn using the ambient load technique.

Measurements made with the cone mounted on the 64-m antenna show that the system temperature increased a further 2.4 K by the ambient load technique.

Reference

1. Stelzried, C. T., "Operating Noise-Temperature Calibrations of Low-Noise Receiving Systems", *Microwave J.*, Vol. 14, No. 6, pp. 41-48, June 1971.

Table 1. Averaged operating noise temperature calibrations for the SRO and PDS cones at GDSCC

Station	DSS 13				DSS 14	
Cone	SRO				PDS	
Configuration	Cone on antenna			Gain standard horn	Low-noise path	Diplexed
Frequency, MHz	2388	2295	2278.5	2278.5	2298	2292
Maser serial number	96S2	96S2	96S2	96S2	96S3	96S3
Maser temperature, K	5.2	5.2	5.2	5.2	4	4
Maser gain, dB	36.7 $\pm 1.31/0.15$ 74 Measurements	51.4 $\pm 0.28/0.20$ 2 Measurements	45.9 $\pm 2.70/0.39$ 49 Measurements	45.6 $\pm 4.13/1.03$ 16 Measurements	53.0 $\pm 0.21/0.15$ 2 Measurements	52.5 $\pm 0.21/0.15$ 2 Measurements
Follow-up noise temperature contribution, K	0.54 $\pm 0.06/0.01$ 60 Measurements	0.08 1 Measurement	0.28 $\pm 0.13/0.02$ 40 Measurements	0.27 $\pm 0.09/0.03$ 12 Measurements	0.02 $\pm 0.001/0.0008$ 2 Measurements	0.03 $\pm 0.0009/0.0006$ 2 Measurements
System operating noise temperature, K	16.9 $\pm 0.40/0.05$ 60 Measurements	16.3 ± 0.20 1 Measurement	18.4 $\pm 0.89/0.14$ 40 Measurements	26.3 $\pm 0.46/0.13$ 12 Measurements	20.2 $\pm 0.26/0.19$ 2 Measurements	24.3 $\pm 0.11/0.08$ 2 Measurements

Table 2. Average operating noise temperature calibrations for the MXK cone on the ground at DSS 13 and on the 64-m antenna at DSS 14

Configuration	DSS 13										DSS 14	
	Cone on ground										Cone on antenna	
	Mod 0	Reference horn	Main horn	Main horn	Main horn	Main horn	Main horn	Reference horn	Reference horn	Reference horn	Subreflector on main horn	Subreflector on PDS cone
Frequency	8427.2	8427.2	8427.2	8427.2	8427.2	8415	8415	8415	8415	8415	8415	8415
Measurement method	Ambient load	Ambient load	Ambient load	Ambient load	Ambient load	Ambient load	Ambient load	Ambient load	Ambient load	Ambient load	Ambient load	Ambient load
Maser temperature, K	7	7	7	7	7	7	7	7	7	7	7	7
Maser gain, dB	35.2 ±1.5/0.50 70 Measure- ments	33.0 ±0.40 1 Measure- ment	No measure- ment	33.0 ±0.17 1 Measure- ment	No measure- ment	No measure- ment	No measure- ment	—	—	—	—	—
Follow-up receiver con- tribution, K	0.28 ±0.04/0.004 70 Measure- ments	0.33 ±0.18/0.07 7 Measure- ments	0.44 ±0.13/0.05 6 Measure- ments	0.38 ±0.20/0.04 29 Measure- ments	0.33 ±0.12/0.03 18 Measure- ments	0.36 ±0.12/0.06 4 Measure- ments	0.42 ±0.10/0.03 9 Measure- ments	0.32 ±0.12/0.07 4 Measure- ments	0.79 ±0.12/0.04 10 Measure- ments	0.82 ±0.04/0.02 6 Measure- ments	—	—
System operating noise temperature, K	17.0 ±0.61/0.07 70 Measure- ments	21.0 ±0.13/0.05 7 Measure- ments	19.0 ±0.47/0.19 6 Measure- ments	18.2 ±0.56/0.10 29 Measure- ments	18.1 ±0.26/0.06 18 Measure- ments	18.8 ±0.32/0.16 4 Measure- ments	20.2 ±0.18/0.06 9 Measure- ments	20.0 ±0.33/0.19 4 Measure- ments	24.0 ±0.24/0.08 10 Measure- ments	30.5 ±0.41/0.17 6 Measure- ments	—	—

Table 3. System operating noise temperature calibrations of the K-band system in various configurations

Configuration	Before cone installation		Cone on ground				Cone mounted on 64-m antenna	
	JPL		DSS-13				DSS-14	
	Ambient load	Aperture load	Ambient load	Aperture load	Ambient load	Reference	Ambient load	Main
Location								
Measurement technique								
Horn								
Follow-up receiver contribu- tion, K	0.15 ±0.09/0.01 56 Measurements	0.14 ±0.08/0.01 56 Measurements	0.16 ±0.09/0.02 17 Measurements	0.13 ±0.07/0.02 11 Measurements	0.62 1 Measurement	0.17	1 Measurement	28.5 ±0.29 2 Measurements
System operating noise temperature	24.8 ±0.79/0.11 56 Measurements	22.6 ±1.07/0.14 56 Measurements	26.1 ±0.55/0.13 17 Measurements	24.5 ±0.37/0.10 11 Measurements	29.1 1 Measurement	29.1	28.5 ±0.29 2 Measurements	—

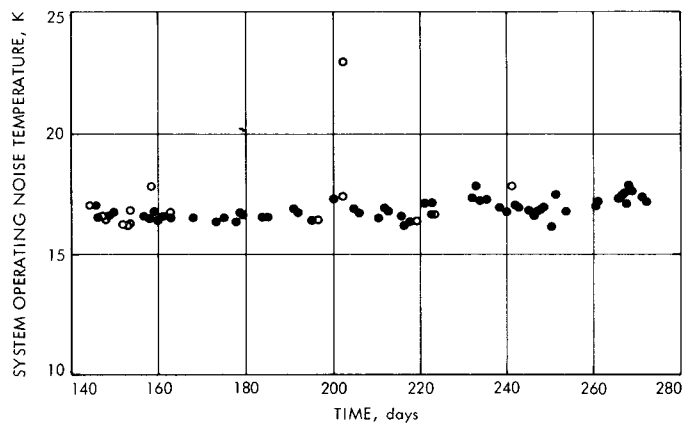


Fig. 1. System operating noise temperatures of the SRO cone at 2388 MHz

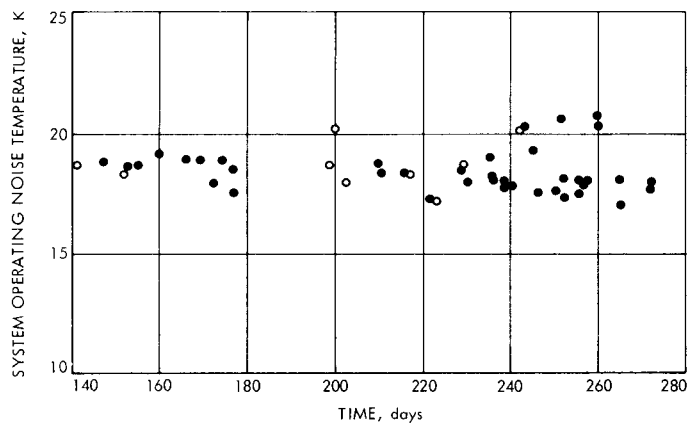


Fig. 2. System operating noise temperatures of the SRO cone at 2378.5 MHz

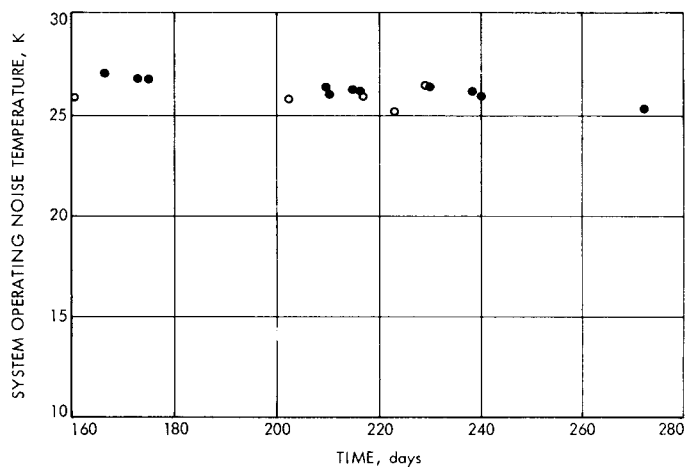


Fig. 3. System operating noise temperatures with the maser connected to the gain standard horn at 2378.5 MHz

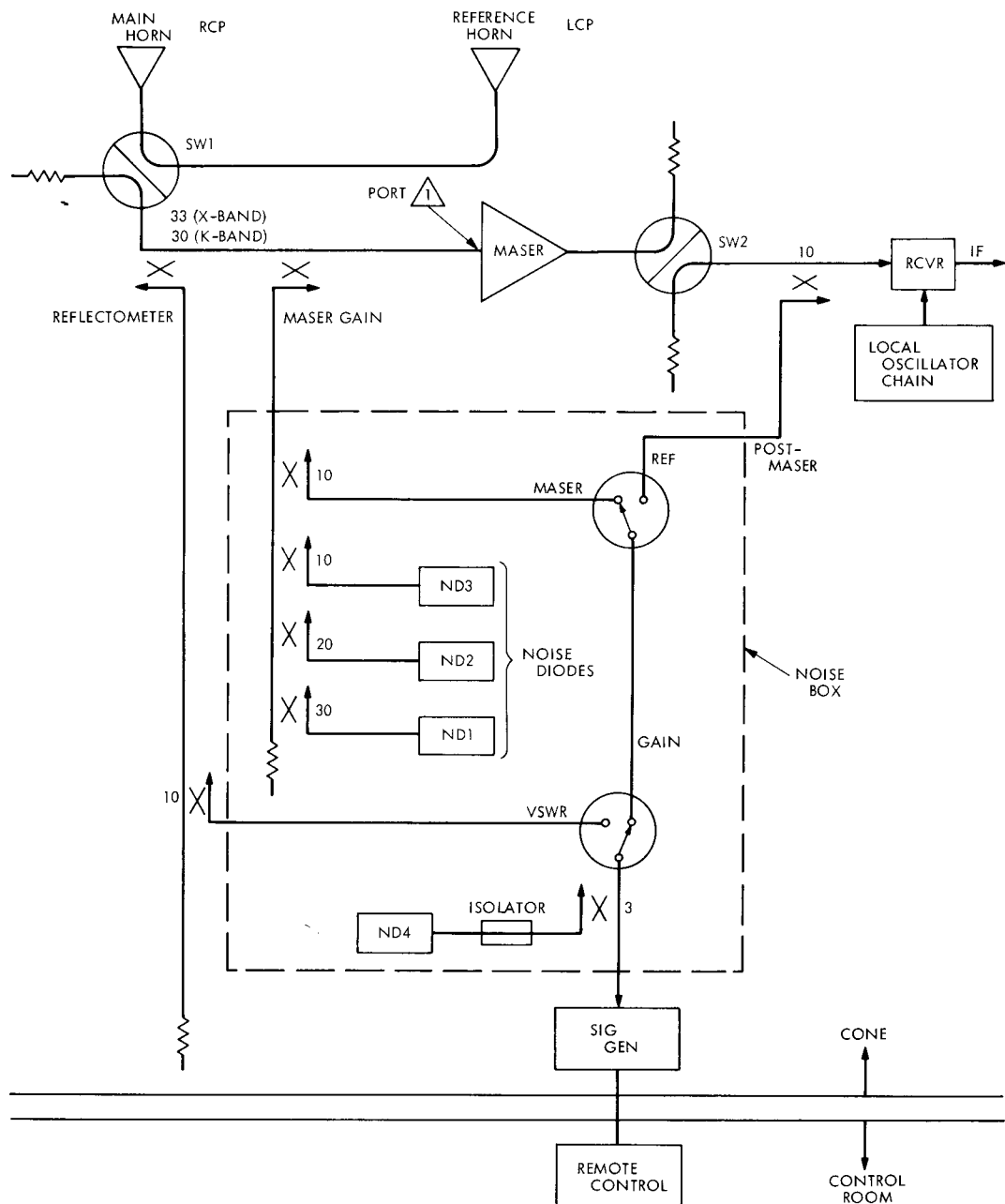


Fig. 4. Simplified block diagram of the X-band and K-band systems in the MXK cone

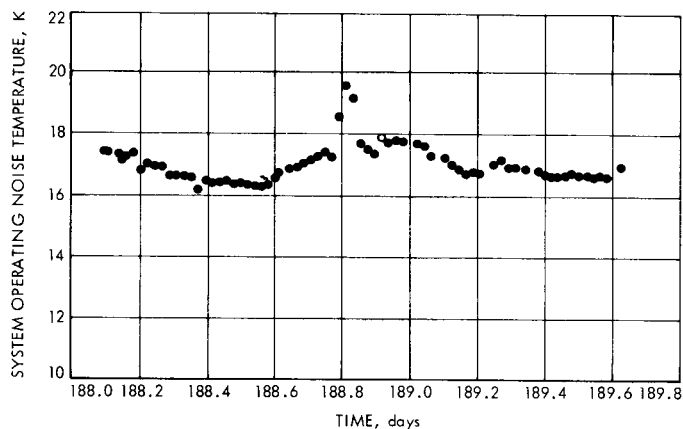


Fig. 5. System operating noise temperatures of the MXK cone (Mod. 0) on the ground at DSS 13 at 8427.2 MHz; ambient load technique

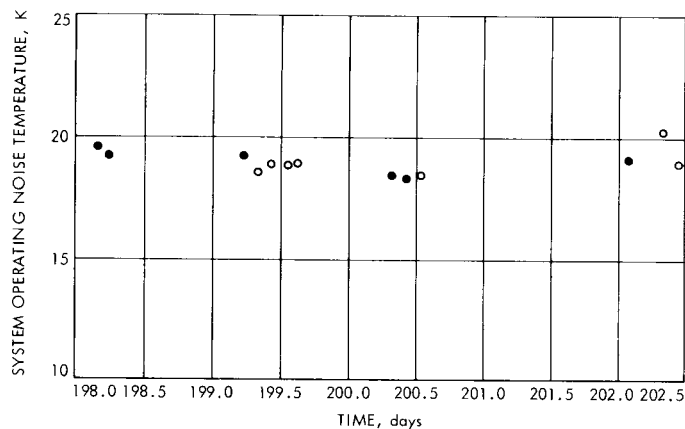


Fig. 7. System operating noise temperatures of the MXK cone (Mod. 1) on the ground at DSS 13 at 8427.2 MHz; main horn; aperture load technique

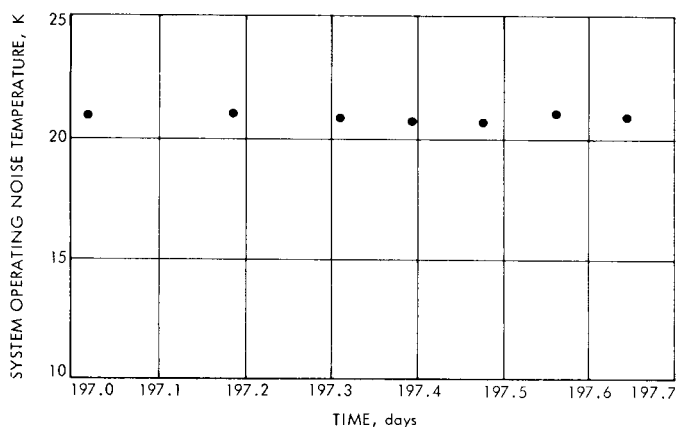


Fig. 6. System operating noise temperatures of the MXK cone (Mod. 1) on the ground at DSS 13 at 8427.2 MHz; reference horn; ambient load technique

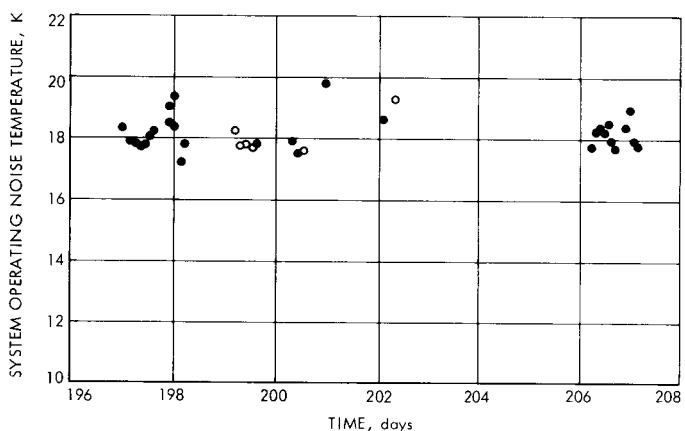


Fig. 8. System operating noise temperatures of the MXK cone (Mod. 1) on the ground at DSS 13 at 8427.2 MHz; main horn; ambient load technique

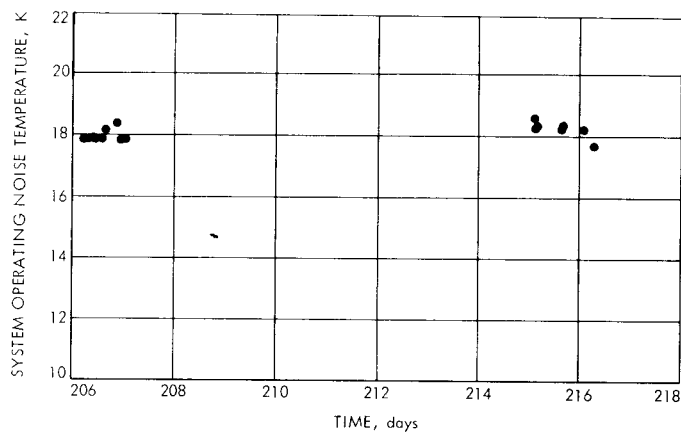


Fig. 9. System operating noise temperatures of the MXK cone (Mod. 1) on the ground at DSS 13 at 8415 MHz; main horn; ambient load technique

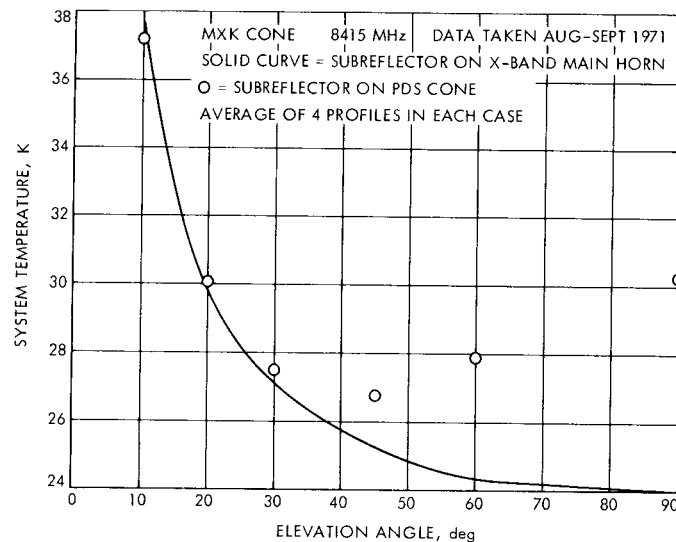


Fig. 11. System temperature profile with antenna elevation angle of the MXK cone (Mod. 1) at 8415 MHz

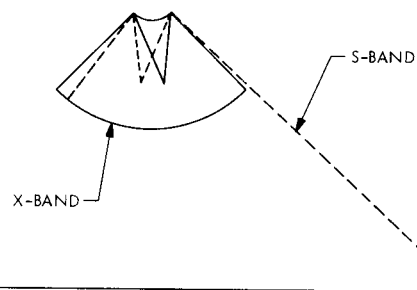


Fig. 12. X-band ray path geometry for the MXK cone with the subreflector focused for X-band and for S-band

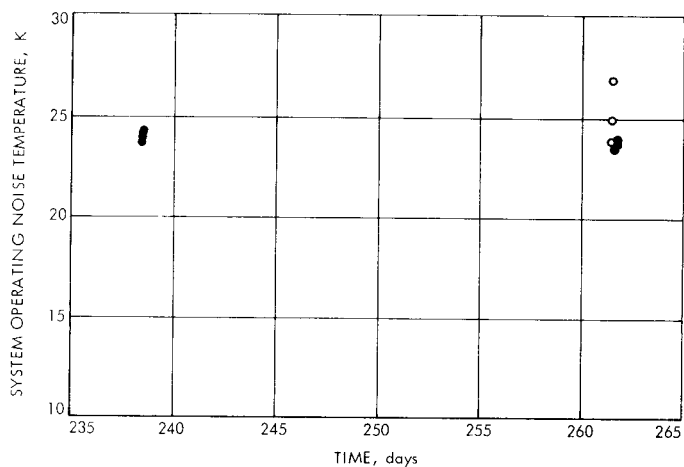


Fig. 10. System operating noise temperatures of the MXK cone (Mod. 1) on the 64 m antenna at DSS 14 at 8415 MHz; main horn; ambient load technique

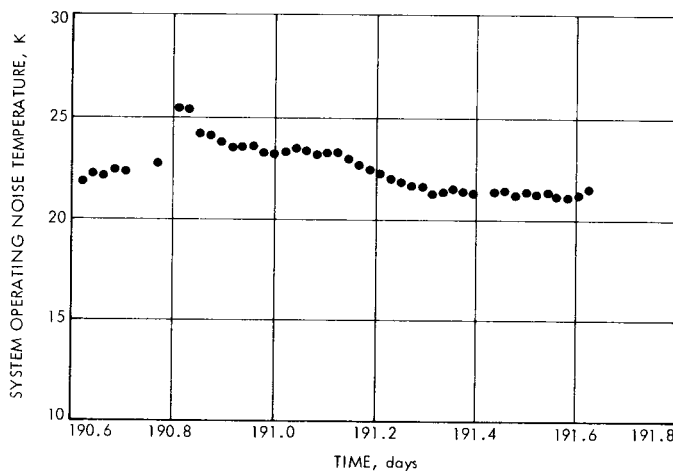


Fig. 13. System operating noise temperature calibrations of the K-band system as a function of time for a 24-hour run; aperture load technique; roof of building 238